1916

Notes on the development of the flotation process for concentrating copper and iron sulphide ore

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NOTES ON THE DEVELOPMENT OF THE FLOTATION PROCESS FOR CONCENTRATING COPPER AND IRON SULPHIDE ORE.

by

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THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY

OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

DEGREE OF

BACHELOR OF SCIENCE IN MINE ENGINEERING

Rolla, Mo.

1916

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of Metallurgy and Ore Dressing.

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Notes on the Development of the Flotation Process for Concentrating Copper and Iron Sulphide Ore.

The first flotation machine was installed at the Magna Mill of the Utah Copper Co. in August and September, 1914. The outbreak of the war in Europe having made necessary the shutting down of the Arthur Mill of the same company, the flotation plant was installed at Magna for the purpose of carrying on experiments which had been in progress at Arthur. Enough experimentation had been done with the small laboratory machine at Arthur, and results obtained were favorable enough to warrant the installation of a full size Janney machine.

The experiments at Magna were therefore begun on a commercial scale. The machine was operated under a load of about 300 tons per 24 hours. The objects in view were the selection of the cheapest and best oils for the ore in hand and the discovery and correction of any faults which might exist in the design of the machine.

There are herewith produced four drawings of the machine. Plate I shows the entire plant in plan after three more machines had been added to the plant in addition to the original machine. The four sludge tanks, Nos. 1, 2, 3, and 4 feed respectively machines Nos. 1, 2, 3, and 4 consisting of seven cells each. There are three preliminary mixing cells ahead of the first cell in machines Nos. 1

and 3. In machines Nos. 2 and 4 the feed passes directly from the sludge tank into the first cell. Each cell is placed six inches below the one preceding so that the feed will pass from one to the other by gravity. A sloping board floor extends from sludge tanks Nos. 1 and 3 down between the two rows of cells. The machines are operated from this.

Plate II shows the mixer casting. Because of the fact that the feed passes from one mixer to the next without any of the mineral being taken out in a spitzkasten, (see Plate IV), this casting is slightly different from those used in the cells. The mixer casting has but one large pipe by which the feed enters at the bottom while the cell casting has two smaller ones.

These castings are made of an inferior grade of cast iron. Each has a liner, also of cast iron, which takes the wear of the pulp and which may be renewed whenever necessary.

Plate III shows the impellor which extends down into each cell and mixer casting. It is rotated at the rate of 560 R. P. M. by a 10 H. P. motor. It is made of cast steel and consists of a shaft and two sets of arms. These arms, four in each set, extend out from the shaft like the blades of a propellor. When the whole is rotated they exert a powerful lifting force, thus drawing the pulp up through the syphons and into the cell, where it is beaten into a froth. The impellor is screwed on to the motor rotary.

Plate IV shows the arrangement of the cell casting, spitzkasten and motor and is a cross section through one of the syphons. This casting is the same as the one for the mixers with the one exception above mentioned.

The theory of the flotation process of concentration is based on the known fact that oil will adhere to the surface of sulphides more readily than it will to the surface of silica. In other words the oil will wet the sulphides and not the silica. This fact has been known for a long time and has, in the past, served as a satisfactory explanation of flotation. Recently however it has been observed by those doing research work that ores having certain common flotation properties have common electrostatic properties. This discovery has led to much experimentation which is going on at the present time. It is believed by many that investigation along this line will eventually lead to the true theory of flotation. As yet I know of no definite conclusions having been reached.

In connection with the affinity of oil for sulphides there is another important consideration. If pure water be placed in a bottle and shaken vigorously for a few moments, air will be forced into the water. On allowing it to stand all these air bubbles will rise to the surface and break immediately. But if a few drops of oil be added to the water the shaking will produce bubbles which on rising to the surface will not break. They form a froth that will not break down even after standing for several hours. It is probable that the oil is contained in the water making the bubbles' films and that when these bubbles come in contact with small particles of sulphide they attach themselves to them and do most of the lifting. The oil itself is not of low enough specific gravity to exert much lifting power. Neither is it in great enough quantity.

Referring now to Plate I, and considering the machine fed from No. 3 sludge tank, the feed from the Callow cones on entering the sludge tank passes through a coarse wire screen to remove pieces of wood, waste, etc. It discharges at the bottom through a molasses gate. The principle amount of oil is added here. It passes through three mixing cells M where it is given a preliminary agitation before it reaches the first cell. No mineral is taken out in the mixers. From the last mixer it goes to the first cell where it is again agitated. By this time it is thoroughly mixed with the oil and a heavy froth has been produced. It is then discharged at the front of the cell casting into the first spitzkasten. The air bubbles created by the violent agitation rise to the surface, bearing part of the mineral and form a froth which is skimmed off. From this spitzkasten the pulp may by sucked up again into cell No. 1 by the two syphons, one of which is shown on Plate IV. or it may pass through a gate in the partition between spitzkasten Nos. 1 and 2. Thus there is a certain amount of circulation between each cell and the spitzkasten in front of it. All the feed however eventually passes into the second spitzkasten and into the second cell, entering the cell through the two syphons. In the second cell it is agitated again, with additional oil if necessary, and discharged into the spitzkasten where the froth rises as in the first. From here it passes on through as many units as the machine may have. The mineral bearing froth is skimmed off from each spitzkasten and the tailing is made from the bottom of the last one.

As the feed passes through the machine it is often necessary to replenish the supply of oil. For this purpose there are two small pipes leading into each cell through which the oil may be added in any desired quantity.

The feed treated was the low grade vanner concentrates from the 4th and 5th spigots and overflow of the concentrate classifiers. It assayed 6 to 9% copper, 5 to 8% iron and 69 to 72% silica. All of this would pass a 40-mesh screen. The feed was first pumped up into twenty Callow cones where it was dewatered to the desired dilution. From the Callow cones it went to the various sludge tanks. The principle minerals were chalcocite, bornite, pyrite and chalcopyrite with some malachite and azurite. The gangue was porphyry and quartzite. The following composite screen analysis covering a period of seven days will give a good idea of the condition of the feed:

Mesh	Per cent. Material by weight	Accumulative per cent. Material by Weight
On 65	1.40	1.40
100	10.42	11.82
150	9.02	20.84
200	16.43	37.27
Thru 200	62.73	100.00

In the above table notice that 62.73 per cent. of the feed is finer than 200 mesh. The amount of slime in the feed was found to have a bearing on the thickness of pulp most desirable. With a high slime feed a dilution of from 4 to 6 of water to 1 of solid by volume was found to give the best results. With a low slime feed a dilution of about 1.5 of water to 1 of solid was sufficient.

With slight changes in the ore the amount of slime would vary considerably. The above screen analysis represents the average feed. I have observed that the thinner the pulp, the cleaner will be the concentrates and, due to the increase of volume of the feed, the more oil is necessary. But as the pulp becomes thicker less oil is needed and the concentrates become more silicious. With a gradually thickening pulp a condition called "over-oiled" is likely to occur . With a very thin feed it is almost impossible to "over-oil" the machine. The thin feed, if allowed to remain thin for any considerable length of time will almost invariably cause high tails. With a thick feed, if it is not so thick as to cause an "over-oiled" condition, the tails will be low. The dilution, as can be seen, is one of the most important things to consider. With the average ore at this plant I have had the best results with a dilution of from 1.7 to 1.9 of water to 1 of solid by volume.

The general conditions of the ore were very favorable for treatment by flotation. The sulphides break comparatively free by crushing through 40 mesh. The surfaces seemed to be clean thus allowing the oil to coat them readily. Due to previous concentration on vanners there was little or no colloidal slime to contend with. The only ore condition that gave trouble was the frequent occurrence of the carbonates, malachite and azurite; these invariably went out through the tail gate.

The experiments were carried on on a large scale. From the beginning the flotation machine was a paying proposition though not until several months after its installation did it reach its highest efficiency. The process was entirely new to us on the operating end and it was necessary for us to become familiar with the mechanics of the machine and learn to estimate with the eye the varying froth conditions before we could have smooth and successful runs. The machine was operated under a rather high tonnage and conditions sometimes changed rapidly. Ore conditions, dilution and amount of oil all played their part in these changes making them obscure and hard to detect.

The oils can be divided roughly into two classes: oils used to give body and lifting power to the froth and oils used to produce a lively frothing action. Oils of the first class are: crude coal tar, coal tar creosotes, wood creosotes, and petroleum products. Oils of the second class are pine oils and turpentine.

The coal tar oils were bought from the Barrett Oil Co. in Salt Lake City. These were known as Acid Tar, Light Oil, No. 92 Creosote, Electro-residuum, and Smelter Fuel. The pine oils used were Cheaspeake Pine and Oregon Pine. The Cheaspeake Pine gave the livelier action and the other was discarded. Turpentine was given a trial of about six days but was found to be inferior to either of the two pine oils and so was discarded.

Experiments for the selection of the best oil were cooducted in the following manner: Each of the oils which served to give body to the froth was taken as the principal oil and was used in quantity. Other oils of the same class were added in smaller and varying quantities as supplementary oils and pine oil was used to give the necessary life to the froth. Thus every possible mixture of oils was given a trial. The length of the runs with each mixture was determined by the success met with or likelihood of success being met with.

The trial run with Electro-residuum was not successful. 95% Electro-residuum and 5% Pine gave a very high tailing of over 1%. Light oil and Creosote were then added in gradually increasing percentages. When a mixture of 12% Electro-residuum, 40% light oil, 40% creosote and 8% pine was reached, the tailing was brought down to .43%. Thus the best tailing made was .1% higher than we had been making with a light oil, creosote, and pine mixture. The Electro-residuum was very thick and much difficulty was had in supplying it steadily to the machine. That possibly accounted in part for the high tail, but was a difficulty not easily overcome, so Electro-residuum was discarded.

Smelter Fuel did not give any more success than Electro-residuum. It was a thick oil and in spite of a steam heating system it would not flow steadily. A mixture of 90% Smelter Fuel and 10% pine gave a tailing of .87% when the oil flow was fairly steady. The addition of light oil and of creosote did not effect the tailing until the Smelter Fuel was practically eliminated--the final mixture being 50% light oil, 35% creosote and a mixture of 50% pine and 50% Smelter Fuel making up the remaining 15%. The oils were run together to secure a more even flow. The above mixture made a tailing of .52%

An oil mixture was discovered after a few unsuccessful trials that included Acid Tar. It was 60% creosote, 20% Acid Tar, 15% light oil, and 5% pine. The mixture when heated flowed steadily which was a great advantage in securing a good run. A tailing of .38% was made. Small percentages of Smelter Fuel and Electro-residuum were added to this mixture toward the end of the run. They gave no effect until they reached about 15% of the total oil, when the tails began to go up. Although the acid tar mixture gave results nearly as good as the best creosote, light oil and pine mixture and is a cheaper oil, it has not been used since the experiment was made.

The oil mixture now in use and the best one so far discovered is 60% creosote, 30% light oil, and 10% pine. This mixture applies to the average ore treated. As the iron content decreases we decrease the percentage of creosote and increase the percentage of light oil. As the iron content increases we increase the amount of creosote and decrease the amount of light oil. The amount of pine oil is placed at 10% in the mixture given above merely to indicate the average amount used. In our practise it is varied by the operator according to the appearance of the froth. Due to the circulation of a middling product the pine oil will frequently accumulate in the machine to such an extent that no pine oil need be added at the mixer. This mixture with its variations gives a tailing that will average .30%.

Turpentine when substituted for pine oil does not give as good a frothing action and results in about a .1% higher tailing.

The above experiments were all made with the machine shown on Plate IV. The amount of oil mixture, now in use, necessary is 1.5 lbs. to 2 lbs. per ton.

The following table is a record of daily runs when the oil mixture, 60% creosote, 30% light oil, and 10% pine was used. The days where no record appears are days when some new oil was being tried; the results of which trials I have already written.

Date	Tons per 24 hrs.	% Cu in Hds.	% Fe in Hds.	% Cu in tails	% Sio_2 in Conc.	Feed Dilution Water to Solid	Oil flow in cc. per 10 sec. in Mixer & cells. 10 cc. per 10 sec. equals 63.5 lbs. in 8 hrs. M	1	2	3	4	5	6	7	Remarks
Nov.8	300	7.01	5.20	.23	9.11	1.7-1	28			2		1			
9	300	8.25	4.17	.31	10.05	2-1	29			2		1		1	
10	250	8.11	3.81	.18	15.24	1.7-1	24			1		1			Load light.
11	300	6.51	6.24	.22	11.60	1.7-1	29			3		1			(Creosote added till (mixture was 80% Creo. (10% light oil, 10% pine.
12	275	7.92	5.56	.24	8.42	1.8-1	26			1		1			
13	350	8.23	5.41	.56	10.50	1.5-1	35			2	1	2	2	1	
14	275	9.10	4.33	.48	9.31	1.6-1	30			1	1	2	1		(Light oil added till (mixture was 40% Creo. (50% light oil, 10% pine.
15	200	9.26	4.87	.17	9.82	1.9-1	21			1		1			Same as for Nov.14th.
16	300	9.24	3.98	.28	9.40	1.8-1	29			3		1			(35% Creo. 55% light oil (10% pine.
17	300	7.64	5.75	.35	9.28	1.8-1	31			2		1			
18	325	7.53	5.92	.35	11.42	1.7-1	34			3	1	2		1	
19	300	7.38	6.04	.22	10.35	1.7-1	27			2		2			
20	300	8.49	3.97	.40	10.30	1.8-1	26			2		2			
24	250	9.96	3.72	.15	11.58	1.7-1	20			4		2			(90% Creo. 10% pine. (No light oil.
25	250	9.09	4.45	.22	11.16	1.7-1	22			5		1			Same as for Nov.24th.
26	300	8.31	4.81	.33	18.21	2.1-1	25			2		1			
27	350	6.49	7.28	.42	9.41	3-1	34		2	2		2		1	Dilution too great.
28	350	7.19	7.01	.38	9.91	1.9-1	37			2		1			
29	350	7.32	6.38	.41	9.28	2.-1	32			2	1	1		1	

In the above table the oil flow recorded for the cells is not exact but an approximation. In the mixer a steady flow was maintained but in the cells it was constantly being changed or cut off altogether so that it was not possible to keep an exact record.

With the original type of spitzkasten, shown in Plate IV the froth was skimmed off by the operator who used a light wooden hoe. It was observed that most of the bubbles rose to the surface within one foot from the back of the spitzkasten. At that point they boiled up violently, slightly raising the surface of the water, and then floated forward toward the lip of the spitzkasten. Instead of going on over the lip the bubbles, now a heavy froth, would compress themselves into a dense heavy mass and begin to settle as more froth piled on top. Thus, unless this mass was raked off constantly by the operator, a great deal of mineral floated would drop away again into the pulp. This condition was most marked in the first Spitzkasten where the froth carried a heavier mineral load, but was noticeable in the second and third also.

With a view to discharge the froth more quickly and prevent the dropping away of the mineral a spitzkasten with an 18 inch opening at the top was designed. It was very similar in design to the original spitzkasten, the principal difference being that it extended only three feet from the cell while the old one extended out five feet. The theory was that all the bubbles would rise in the 18 inch opening and be pushed over the lip by those behind before they would consolidate into a heavy mass. This spitzkasten was put on a machine of ten cells. In operation the froth discharged as expected, but apparently all of the bubbles did not rise within the 18 inch space for the tails were much higher than on the old machine.

To meet with the difficulty a mechanical skimmer was attached to the front of each spitzkasten of the original type. This gave a continuous discharge of froth and little trouble was had with the heavy masses.

As a general thing machine No. 3 treated about 300 tons per 24 hours. The froth from the first cell was very heavy with mineral and very dense. The next three cells produced a froth that was considered to be more normal. Its mineral load was not so heavy and the bubbles were a little larger. While the mechanical skimmers removed the froth at a fair rate it was apparent that mineral was still dropping away from the heavy froth on the first spitzkasten. By decreasing the tonnage slightly this froth improved greatly in appearance and a lower tail was made. The runs for Nov. 10, 15, 24, as shown in the table illustrate this. Instead of decreasing the tonnage to make lower tails, why not increase the area within which the bubbles could rise and form the froth? That would divide the mineral load in the froth according to the ratio of increase of area. So another spitzkasten was put on each cell. The cell casting was altered to provide for two more syphons leading up from the additional spitzkasten which was placed at the back of the cell. In other respects the casting was the same as in Plate IV. To keep the water levels at the same height in each pair of spitzkasten two slots, 4 by 6 inches were made connecting them below the water level. This gave an equal pull on all four syphons.

This new machine consisted of nine cells instead of seven as in the old one. Operations were begun under a 350 ton load. The froth was much better than on the old machine when operated under an equal load. After slight difficulties in operation were overcome the machine made much better tails. The tailing consistently averaged .2% copper and often a tailing of .1% copper was made for a run of eight hours. The silica in the concentrates was increased about three percent due to there being a greater number of spitzkasten discharging to high grade. That is, there were, on this new machine, twice the number of spitzkasten and twice the amount of froth bearing the concentrates as on the old machine. This extra amount of froth carried the extra silica.

During the cold weather it was thought that perhaps heating the feed would be an advantage. Accordingly steam pipes were put in the sludge tank feeding machine No. 3 and the feed heated to 75 degrees F. This gave no noticeable improvement. On heating to 100 degrees F there was still no improvement in the results obtained so it was concluded that heating the feed was of no advantage.

When the machine with the single spitzkasten was in use and the tails were running up close to .4% it was noticed that the last two cells did not produce much froth. It was thought that by increasing the speed of the impellor a better agitation would be obtained and more froth formed. So a motor making 850 R. P. M. was put on the last cell. The agitation was too violent. The pulp was discharged into the spitzkasten with such force that the water there boiled up and prevented the formation of any froth whatever.

I N D E X

Plate I.

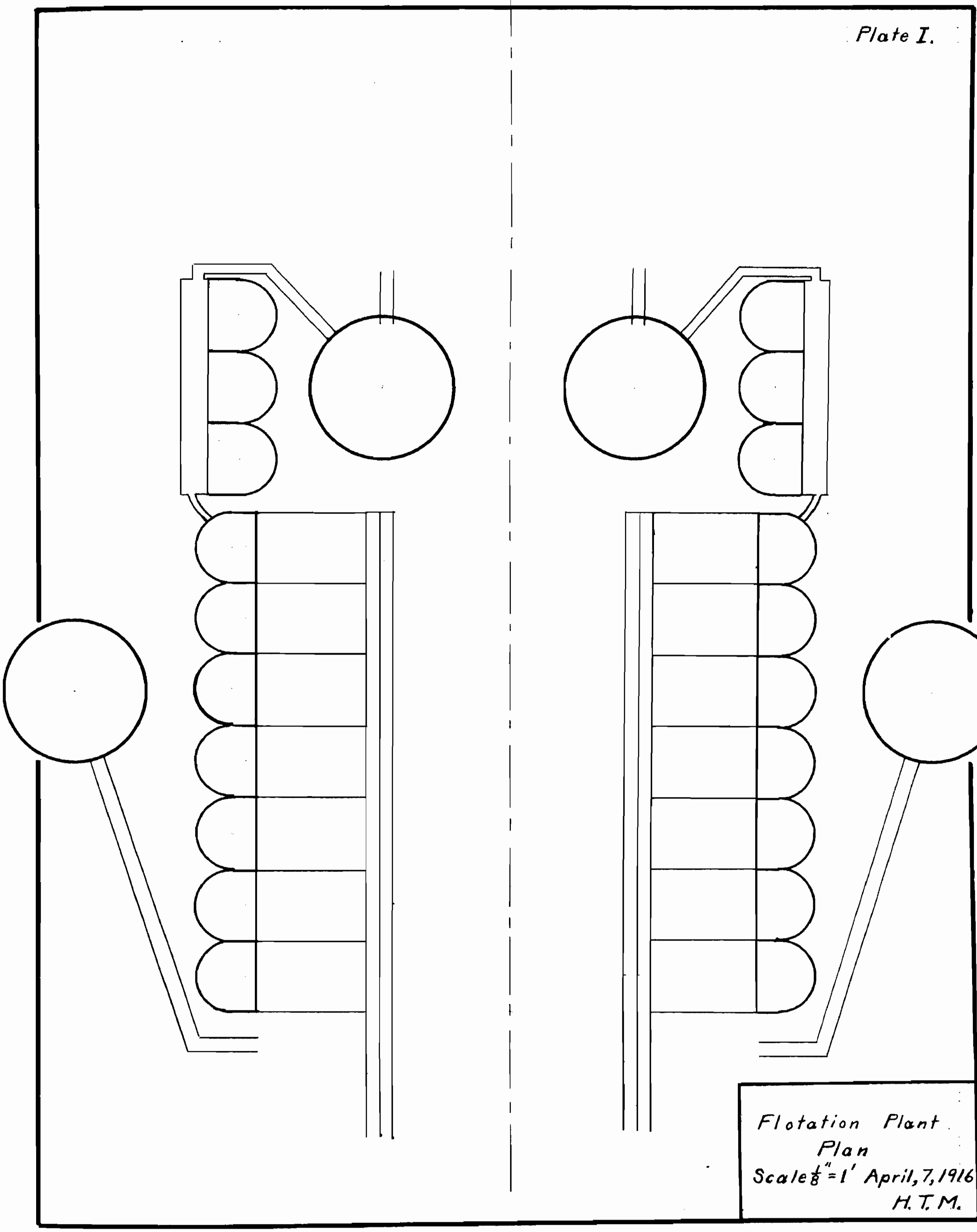
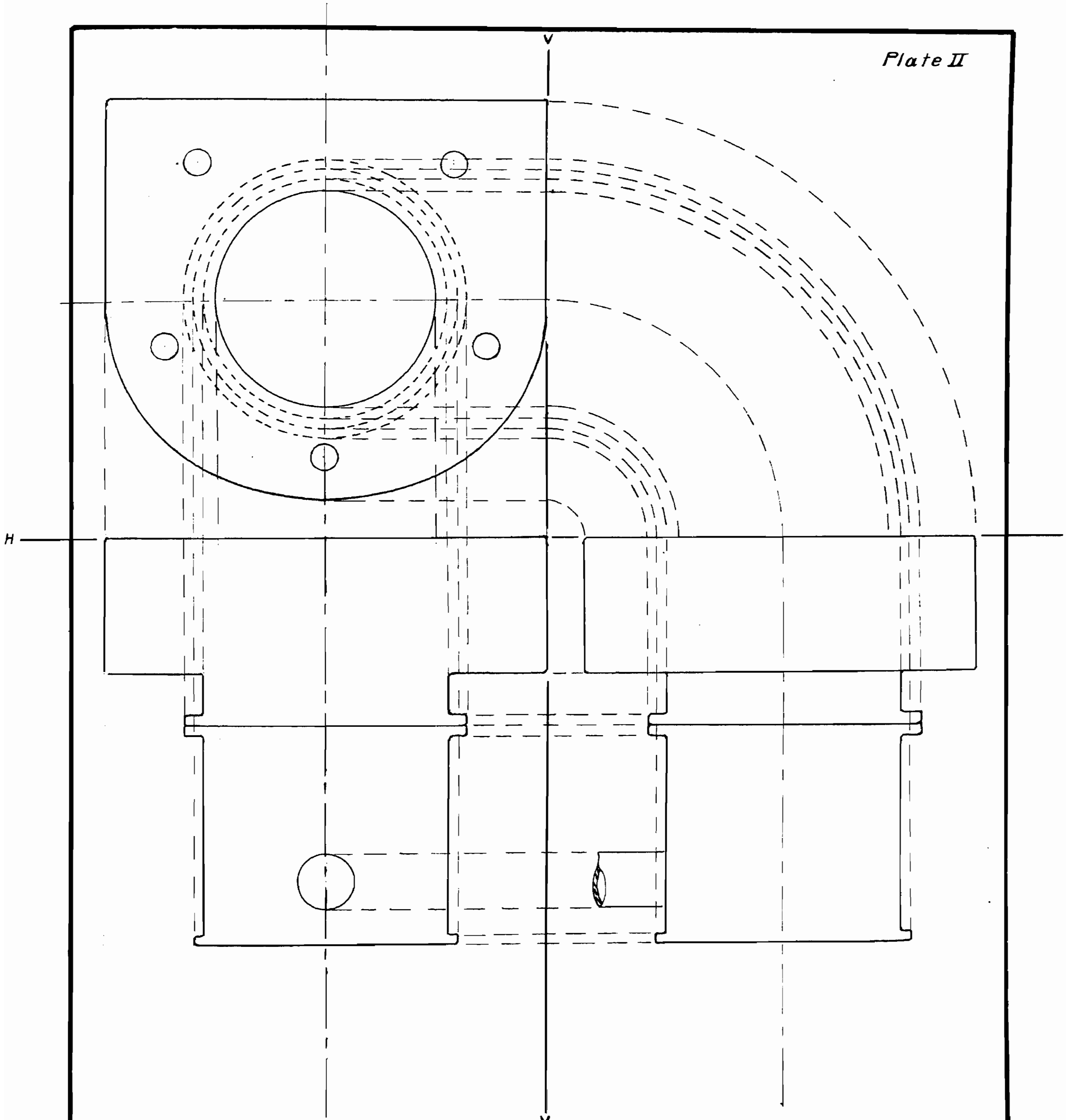
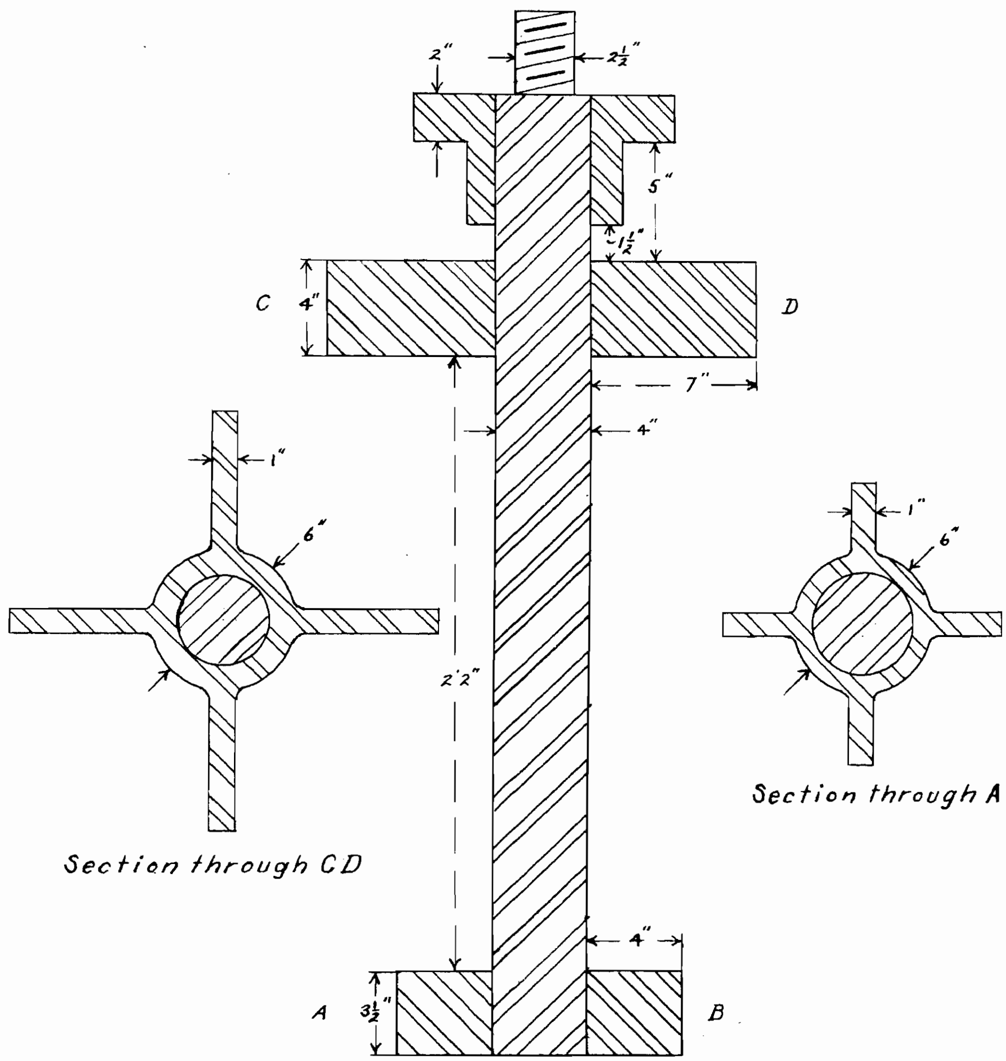


Plate II



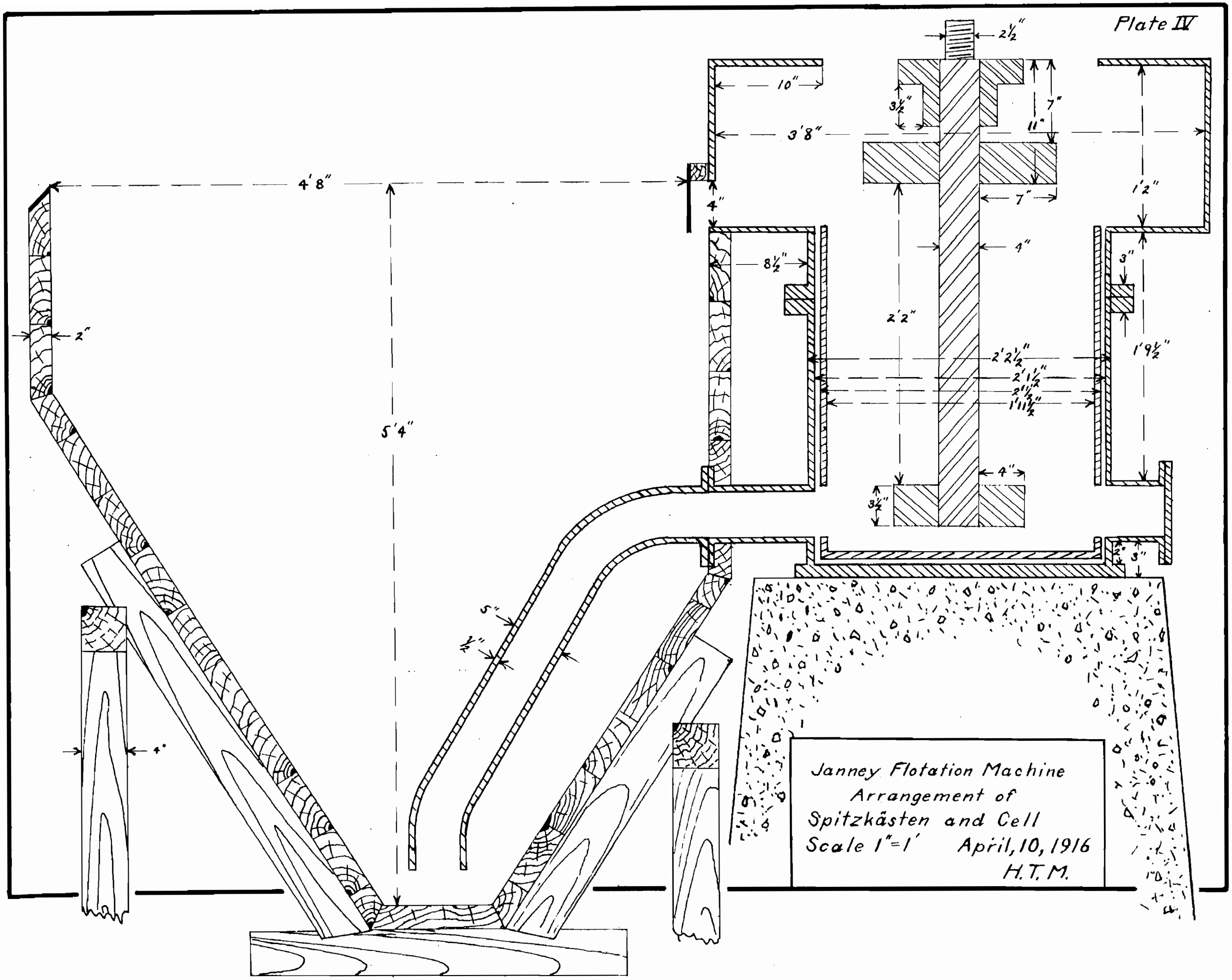
Janney Flotation Machine.
Mixer Casting. Scale $\frac{3}{4}$" = 1'
April, 7, 1916. H.T.M.

Plate III



Janney Flotation
Machine.
Impellor. Scale 1½" = 1'
April 25, 1916 H.T.M.

Plate IV



Janney Flotation Machine
Arrangement of
Spitzkästen and Cell
Scale 1"=1' April, 10, 1916
H.T.M.